

# Single Atom Optical Clocks

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In recent years, several groups throughout the world have initiated research toward the development and systematic evaluation of frequency and time standards based on narrow optical transitions in laser-cooled atomic systems. I will discuss some of the key ingredients to the make-up and operation of single atom, optical clocks and why they offer higher stability and accuracy than the best clocks of today. I will then present some of the results obtained at NIST through comparative studies of the Hg<sup>+</sup> single ion optical clock, the Al<sup>+</sup> single ion optical clock and the Cs fountain, primary frequency standard (NIST-F1) [1-4]. The frequencies of the clocks are compared with each other using an octave-spanning optical frequency comb (OFC), which is tightly phase locked to one of the clock lasers. The most recent frequency comparison between the Hg<sup>+</sup> optical clock and NIST-F1 shows an uncertainty of  $\sim 9 \cdot 10^{-16}$  limited by the integration time, and recent measurements of the frequency ratio between the Al<sup>+</sup> and Hg<sup>+</sup> standards show an overall uncertainty of several parts in  $10^{-17}$ . The extremely precise measurements of the frequency ratios of these clocks over time have begun to offer more stringent limits on any temporal variation of the fine structure constant  $\alpha$  as well as other tests of general relativity.

## References:

- [1] W. H. Oskay, S. A. Diddams, E. A. Donley, T. M. Fortier, T. P. Heavner, L. Hollberg, W. M. Itano, S. R. Jefferts, M. J. Delaney, K. Kim, F. Levi, T. E. Parker, and J. C. Bergquist "Single-Atom Optical Clock with High Accuracy" *PRL* **97**, 020801 (2006).
- [2] T. Rosenband, P. O. Schmidt, D. B. Hume, W. M. Itano, T. M. Fortier, J. E. Stalnaker, K. Kim, S. A. Diddams, J. C. J. Koelemeij, J. C. Bergquist, and D. J. Wineland, "Observation of the  $^1S_0 \rightarrow ^3P_0$  Clock Transition in  $^{27}\text{Al}^+$ ", *PRL* **98**, 220801 (2007).
- [3] T. M. Fortier, N. Ashby, J. C. Bergquist, M. J. Delaney, S. A. Diddams, T. P. Heavner, L. Hollberg, W. M. Itano, S. R. Jefferts, K. Kim, F. Levi, L. Lorini, W. H. Oskay, T. E. Parker, J. Shirley, and J. E. Stalnaker "Precision Atomic Spectroscopy for Improved Limits on Variation of the Fine Structure Constant and Local Position Invariance", *PRL* **98**, 070801 (2007).
- [4] T. Rosenband, D. B. Hume, P. O. Schmidt, C. W. Chou, A. Brusch, L. Lorini, W. H. Oskay, R. E. Drullinger, T. M. Fortier, J. E. Stalnaker, S. A. Diddams, W. C. Swann, N. R. Newbury, W. M. Itano, D. J. Wineland, and J. C. Bergquist, "Frequency ratio of Al<sup>+</sup> and Hg<sup>+</sup> single-ion optical clocks; Metrology at the 17th decimal place," *Science* **319**, 1808 - 1812 (2008).